DALMO VICTOR:

POSITIONING A MICROWAVE DIODE

Microwave switches for Apollo antennas had to withstand a temperature range of 140 degrees and high vibration levels during lift-off. Problems and solutions are discussed in this case.

 Prepared for the Stanford Engineering Case Program by Miss Sue Hayes and Mr. R. Ganeriwal with the support of the National Science Foundation. The assistance of Mr. Bob Kindred is gratefully acknowledged.

Dalmo-Victor: Positioning a Microwave Diode

"We had to be sure that all parts of our Apollo antennas would perform very reliably," commented engineer Bob Kindred, "because an in-flight failure of one of our antennas could have disastrous consequences for an Apollo mission." Bob was the lead mechanical engineer for the Apollo antenna at Dalmo Victor, a Textron division, which had been granted the contract to design and develop antennas for the Apollo missions.

The Apollo antenna was actually an array of four 31-inch diameter parabolic antennas clustered around an 11-inch square horn (see Figure 1). This system is more efficient and more

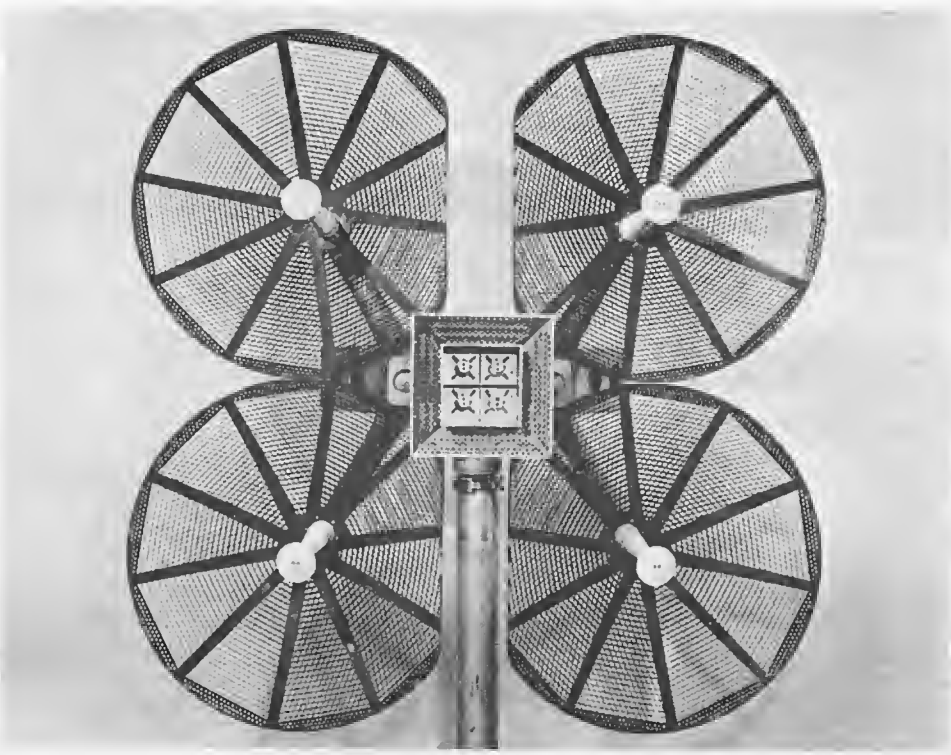


Figure 1. The Antenna Array

flexible than a single antenna because the shape of the beam transmitted to Earth can be changed by operating different combinations of the antenna elements. Close to Earth, the square horn transmits a beam which reaches a large portion of the Earth's surface. As the spacecraft moves away from the Earth, much of the wide beam signal from the horn is no longer intercepted by the Earth, and power is wasted. The signal then switches from the horn to a single, medium beam width parabola. Near the moon, all four parabolas are used together to produce a narrow beam (see Figure 2). "Strip lines" consisting of

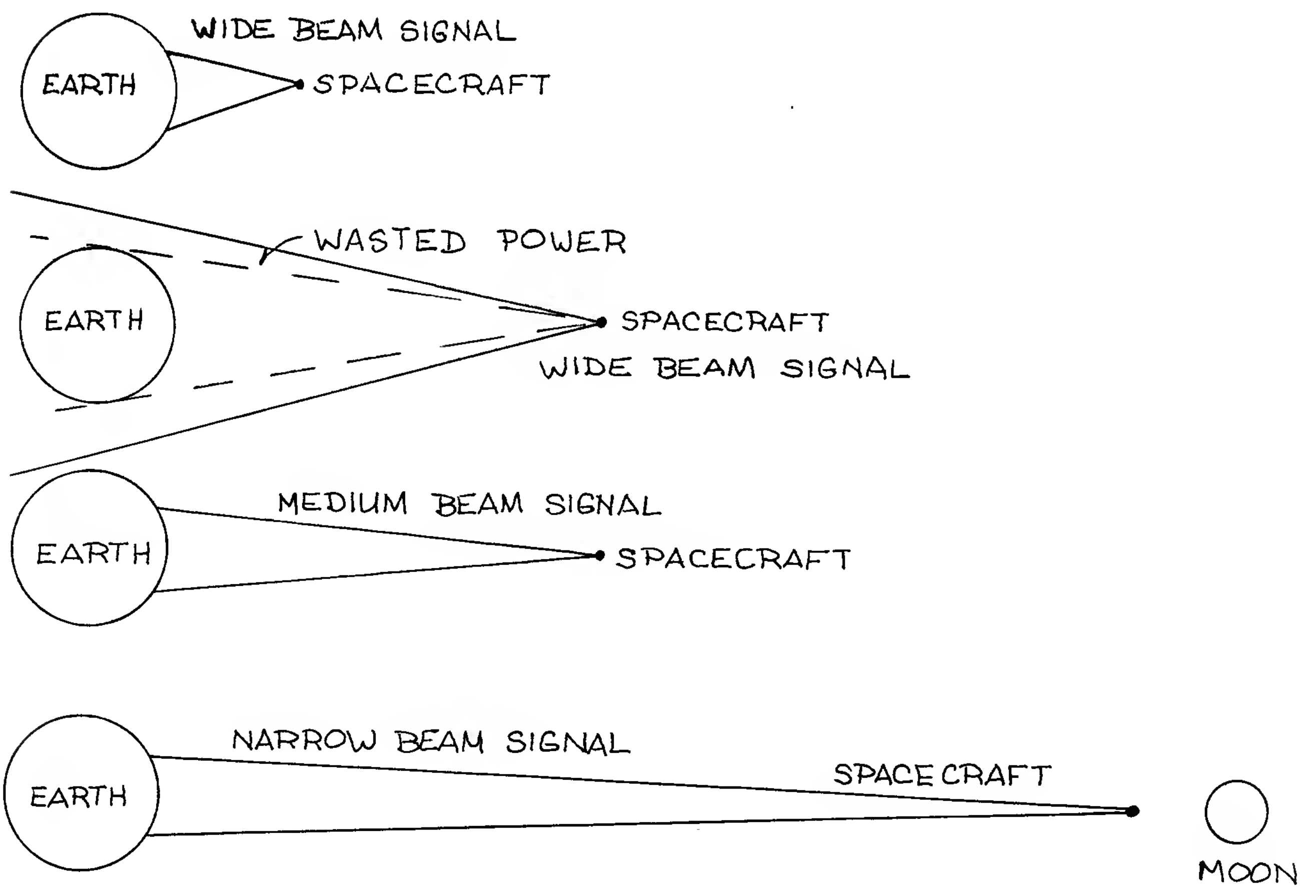


Figure 2
Switching from the Wide Beam to the Narrow Beam Mode

microwave logic circuitry determine when the antenna should be switched from one operating mode to another. The strip lines contain numerous microwave switches, and it was these switches which presented Mr. Kindred with design problems. The tolerance build-up of the switch components had to be controlled over a 140 degree temperature range. The fact that the components were made of a variety of materials complicated the problem. There were also additional design constraints placed by other engineers.

The microwave switches contained diodes which physically consisted of a cylinder of ceramic sandwiched between two metal caps (see Figure 3). One end of each diode had to maintain

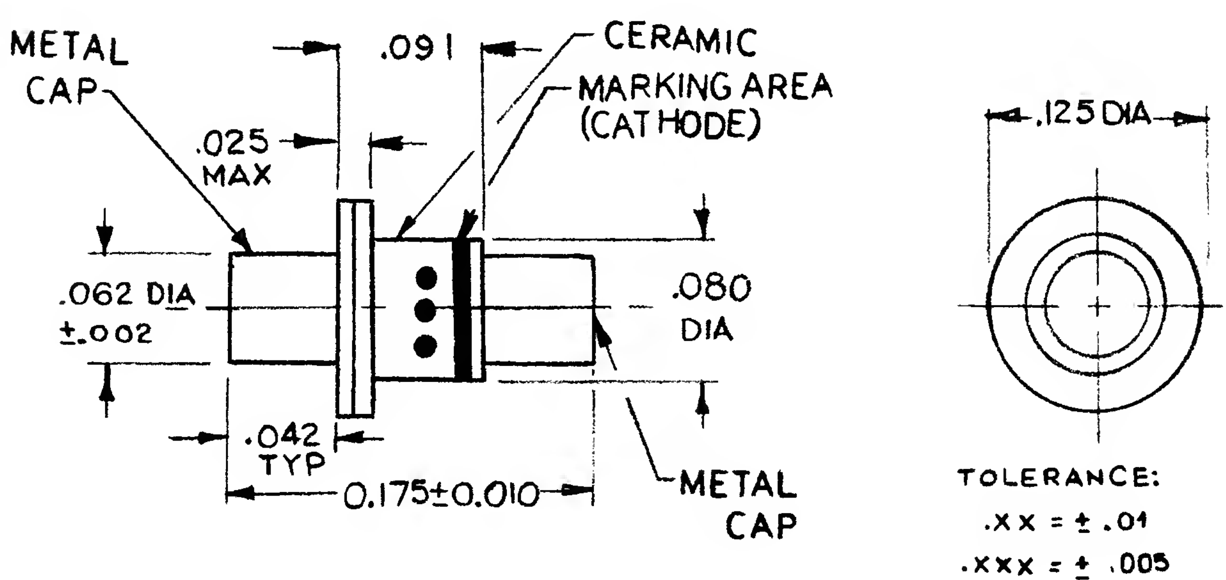


Figure 3
Microwave Diode

good electrical contact with the inner conductor of a coaxial cable. The inner conductor was a metal cylinder, and the outer conductor of the "cable" was actually the metal housing of the switch. Because the diode caps were metal while the center was ceramic, the diodes could not be rigidly mounted to the inner conductor because the difference in thermal expansion rates of the materials might cause the ceramic to crack. The engineers decided to establish contact between the diodes and the inner conductor by drilling a hole in the inner conductor and pushing the diode caps into each end of the hole (see Figure 4). The diodes had to be arranged end to end but with opposite polarities, as shown in Figure 4. Mr. Kindred's problem was to devise a method of keeping the diodes pushed firmly into the hole. High vibration levels during lift-off increased the danger that the diodes might shake loose, and the differing thermal expansion coefficients of the materials precluded rigid mounting of the diodes.

Behind each diode was a retainer. A hole in the retainer positioned and supported the diode. The opposite end of the retainer was threaded, and a nut which traveled back and forth along the threads provided a needed source of adjustable capacitance. The nut was one capacitor "plate" and the housing itself was the other plate. A thin teflon dielectric shield separated the nut from the housing (see Figure 5). Nylon pins driven through holes in the housing and corresponding holes in the retainers held the retainers in place. The pins had to be

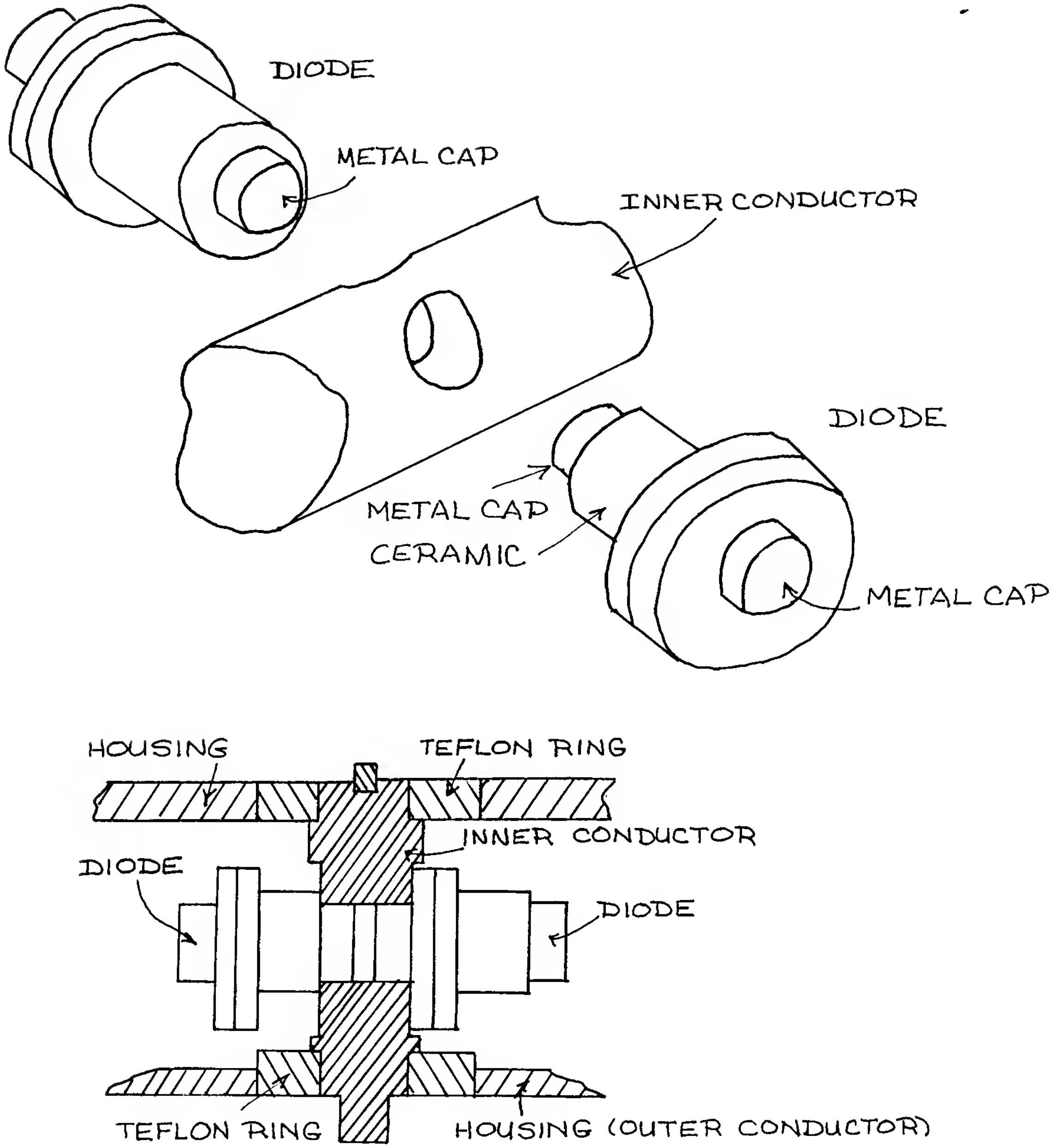


Figure 4. Diodes and Inner Conductor

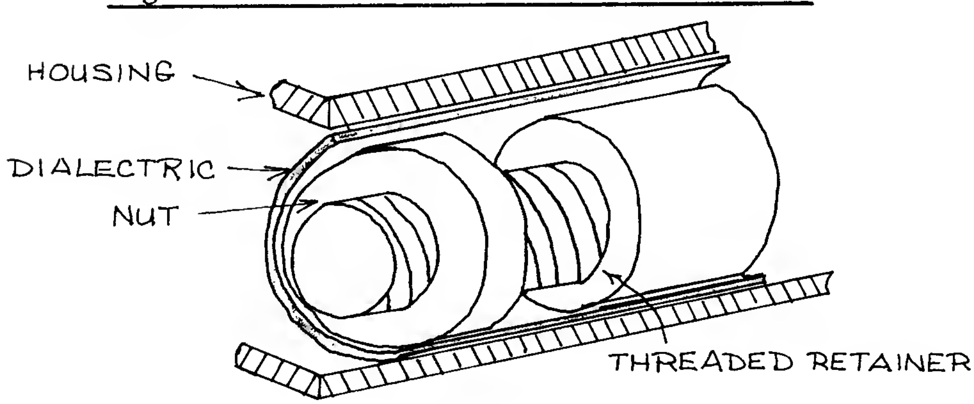


Figure 5
Threaded Retainer with Nut Providing Adjustable Capacitance

nylon or some similar material to prevent the pins from interfering with the electrical performance of the switch. While the retainer supported the end of the diode which was not in contact with the inner conductor, the retainer did not press the diode into the hole (see Figure 6). Some quick initial

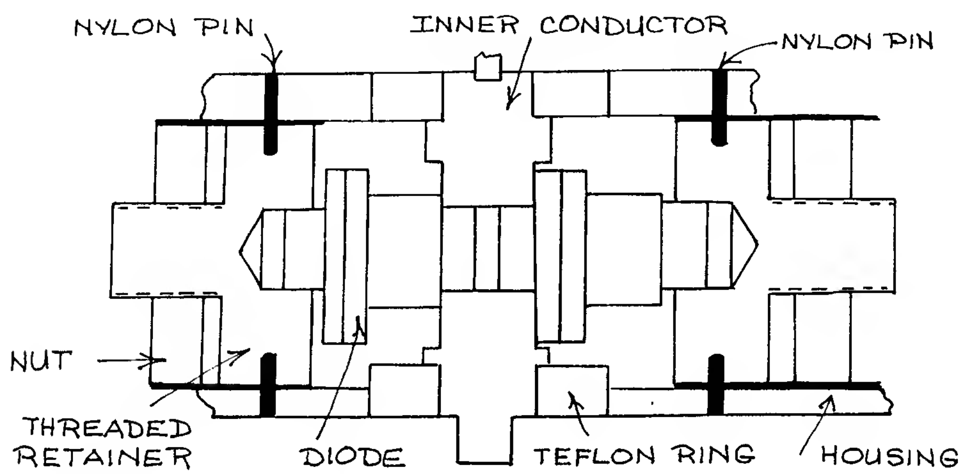


Figure 6
Diodes Supported by Retainers

calculations had shown that it would be impossible to specify tolerances on the various components in order to produce one pound of force pushing the diode into the hole while at the same time having a force that would never be great enough to crack the ceramic within the expected temperature range. The fact that the nylon pins would cold-flow further complicated Bob Kindred's problem. If the retainer pressed the diode into the hole, thermal expansion of the diode might apply a force on the retainer great enough to cause the nylon pins to cold-flow. When the diode contracted to its original shape, the retainer

would no longer press it into the hole (see Figure 7). Also, the diodes were purchased parts, so Bob had no control over the tolerances on their dimensions. To demand tighter tolerances from the manufacturer would have been very costly.

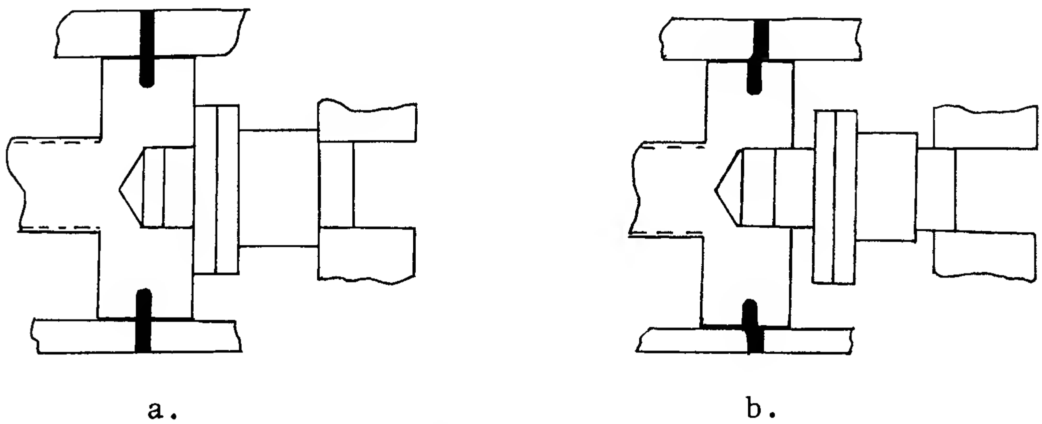


Figure 7
a. Diode Pressed into Inner Conductor by Retainer.
b. Pins Cold-flow, Retainer No Longer Presses Diode into Conductor.

The first solution which Bob and the mechanical engineers tried was to place a bellows type spring between the diode and the retainer (see Figure 8). The bellows had a lot of travel and could easily take up slack caused by thermal contraction or by cold-flow of the nylon pins. Unfortunately, the bellows were so delicate, due to their tiny size, that they damaged easily and were not reliable.

Next, Mr. Kindred tried using a serrated washer, or "finger" spring (see Figure 9), in place of the bellows. The washer, which functioned as a spring and was placed in the same position the bellows had occupied, was much less delicate than the bellows. Unfortunately, eddy currents induced in the washer seriously

interfered with the electrical performance of the switch whenever the washer left flatness. Mr. Kindred also experimented with a Belleville washer, which has a truncated cone shape (see Figure 10). The Belleville washers had spring constants which

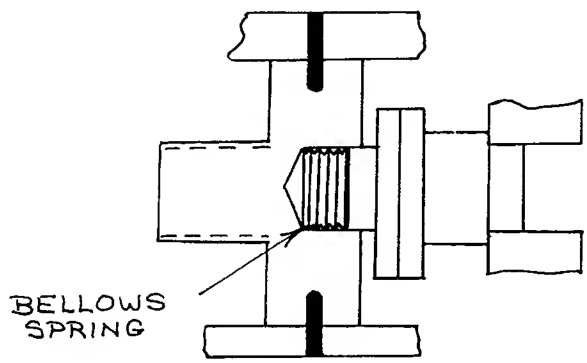


Figure 8
Bellows Spring Positioned in the Retainer

Figure 9
Serrated Washer, or "Finger" Spring

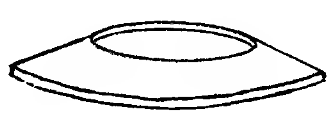


Figure 10
Belleville Washer

were too high. A relatively small travel of the spring would cause a large change in the force applied by the spring. Mr. Kindred finally decided to use a bowed (curved) washer (see Figure 11). This spring did not interfere with electrical

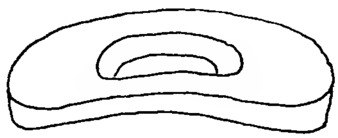
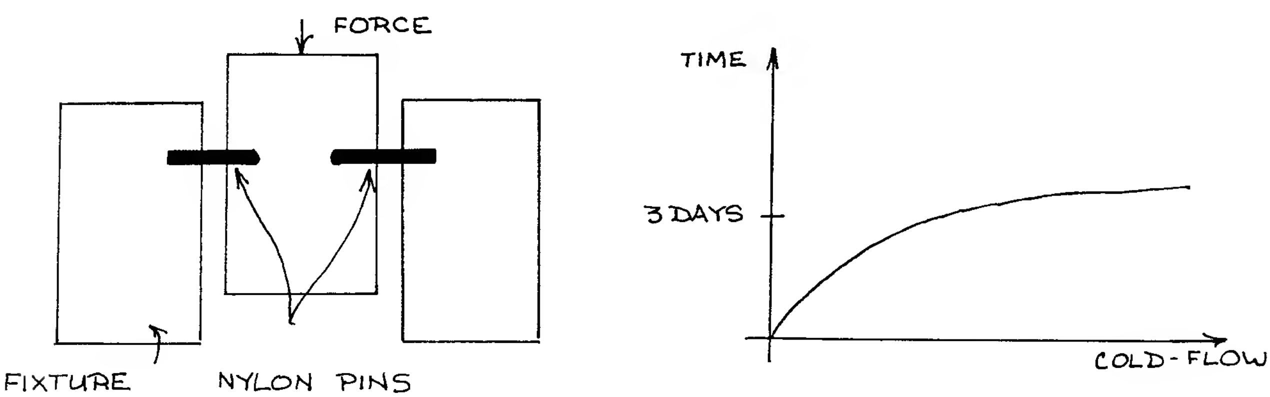


Figure 11
Bowed Washer

performance, was not particularly delicate, and had an appropriate spring rate. It also had good memory of its shape: after being pressed flat, it would readily return to its bowed shape upon release.

After finding a suitable spring, Mr. Kindred began to experimentally determine some of the properties of the nylon pins. He placed nylon pins in a fixture and applied various shear forces to the pins (see Figure 12), and then measured



a. b.

Figure 12
a. Test Set-up for Producing Cold-flow.
b. Time versus Cold-flow.

the cold-flow. The bowed washer had less travel than the bellows, but there was still the possibility that excessive cold-flow of the pins would result in a poor connection between the diode and the inner conductor.

Bob eventually devised an assembly procedure (see Exhibit 1 for this procedure) which solved the problem. The switch, without the washers and retainers, was placed in an assembly fixture. The retainers and diodes were then inserted without the springs, and screws were brought to bear on the ends of the retainers. Torque wrenches measured the force against the retainers, and the screws were positioned to give a certain force on the retainers. Holes for the nylon pins were drilled in both the housing and the retainers while thus assembled. This eliminated the tolerance build-up problems. The retainers were removed and color-coated so they could be matched with their particular housings again. The parts were ultrasonically cleaned and deburred. Next, the parts were reassembled, and this time, the springs were inserted and pressed flat by the force the fixture applied to the ends of the retainers. The presence of the springs caused a .003" misalignment of the matched holes. The nylon pins were forced into the holes, and the misalignment quickly began to cause the pins to cold-flow. As the pins flowed, the washer left flatness and eased some of the force on the pins. After a few days, the pins had come close to the limit of their flow, and the force on them was small. The spring was in a position to accommodate thermal

contraction or expansion without danger of extensive nylon cold-flow (see Figure 13), and the diode continued to be pressed firmly into the inner conductor.

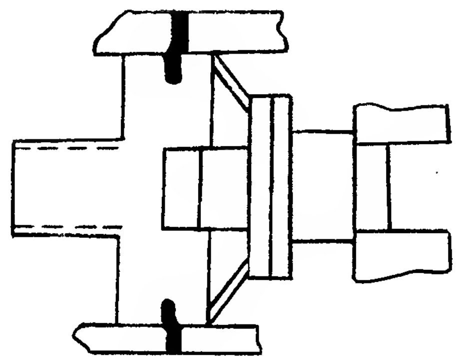


Figure 13
Washer Leaves Flatness as Nylon Pin Cold-flows

Mr. Kindred put several switches through temperature and vibration tests, and they performed successfully. In July of 1969, Apollo 11 went to the moon with the Dalmo Victor antenna array on board, the third lunar flight for the antenna. The successful functioning of the antenna contributed significantly to man's first step on the moon.

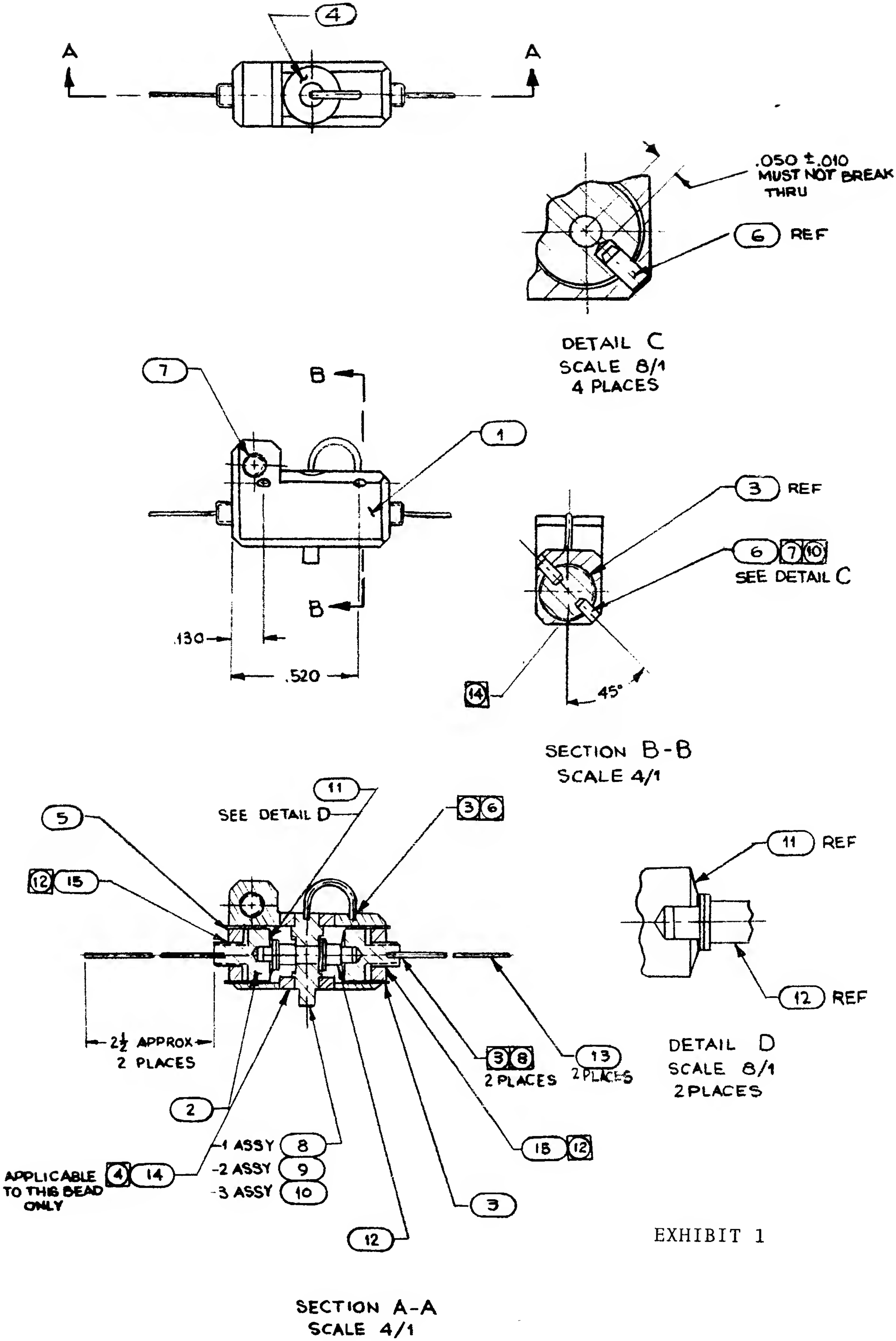

A
A
4
.050 ± .010
MUST NOT BREAK
THRU
6 REF
DETAIL C
SCALE 8/1
4 PLACES
7
B
B
1
.130
.520
3 REF
6 7 10
SEE DETAIL C
14
45°
SECTION B-B
SCALE 4/1
11
SEE DETAIL D
5
3 6
12 15
11 REF
12 REF
2½ APPROX
2 PLACES
3 8
2 PLACES
13
2 PLACES
DETAIL D
SCALE 8/1
2 PLACES
2
-1 ASSY 8
-2 ASSY 9
-3 ASSY 10
15 12
APPLICABLE
TO THIS BEAD
ONLY
4 14
3
12
SECTION A-A
SCALE 4/1

EXHIBIT 1

1. INTERPRET DIMENSIONS, ETC., IN ACCORDANCE WITH LISTED DOCUMENTS AS FOLLOWS:

   DIMENSIONS AND TOLERANCES MIL-STD-8
   SURFACE ROUGHNESS MIL-STD-10
   ABBREVIATIONS MIL-STD-12

2. THIS PART TO MEET ALL REQUIREMENTS FOR IDENTIFICATION AND TRACEABILITY FOR SPECIFICATION. SEE TABLE BELOW.

$\boxed{3}$ SOLDER PER SPEC NPC-200-4 AS AMENDED BY MSC-ASPO-SGA. CLEAN PER DV-PEW-18, METHOD I, FOLLOWED BY METHOD III, ALT 1.

$\boxed{4}$ BOND BEAD (ITEM 4) TO HOUSING (ITEM 1) AND INNER CONDUCTOR (ITEM 8,9, or 10) USING ADHESIVE (ITEM 14) WITH 1% BLACK PIGMENT CONCENTRATE ADDED. BONDING SHALL BE DONE TO THE INNER AND OUTER DIAMETER ONLY OF THE BEAD AS SHOWN. ADHESIVE SHALL BE APPLIED VERY SPARINGLY TO ELIMINATE COATING OF ADJACENT SURFACES. TEFLON BEAD SHALL BE ETCHED PER DV-PST-63 PARA 4.15 NOT MORE THAN 8 HOURS PRIOR TO BONDING; CURE ADHESIVE FOR 2 HOURS AT 165°.

5. THE INNER CONDUCTOR (ITEM 8,9, or 10) SHALL BE POSITIONED DURING BONDING AND SOLDERING SO THAT THE CENTER HOLE IN THE CONDUCTOR IS CENTERED AND IN ALIGNMENT WITH THE .234/.235 DIA. LENGTHWISE HOLE IN IN HOUSING (ITEM 1).

$\boxed{6}$ THE WIRE LOOP OF INNER CONDUCTOR (ITEM 8,9, or 10) MUST BE BOTTOMED IN HOLE IN HOUSING (ITEM 1) WHEN SOLDERED.

$\boxed{7}$ DRILL .0490/.0505 DIA. TO DEPTH SHOWN FOR PINS (ITEM 6).

   a. DRILLING SHALL BE DONE WITH SPRING (ITEM 11) IN PLACE.

   b. PARTS SHALL BE MATCH-MARKED AND KEPT IN SETS TO INSURE THAT IDENTICAL PARTS ARE RE-ASSEMBLED WITHOUT ROTATION.

   c. DRILLED HOLES SHALL BE CAREFULLY DEBURRED AND ALL CHIPS BE REMOVED.

$\boxed{8}$ LEAD WIRES (ITEM 13) SHALL BE SOLDERED TO RETAINERS (ITEM 2) PER NOTE 3. THIS SHALL BE DONE PRIOR TO ASSEMBLY OF RETAINERS INTO HOUSING (ITEM 1).

9. ALL PARTS SHALL BE THOROUGHLY CLEANED PRIOR TO FINAL ASSY.TO INSURE THAT THERE IS NO SOLDER FLUX OR METAL CHIPS AND TO INSURE THAT ALL ELECTRICAL CONTACT SURFACES ARE CLEAN.

$\boxed{10}$. PINS (ITEM 6) SHALL BE INSERTED SO THAT THEY ARE FLUSH OR BELOW FLUSH WITH ADJACENT SURFACE OF HOUSING (ITEM 1).

11. TEST ASSY.PER THE REQUIREMENT OF SPEC 98711. SPECIAL ATTENTION SHALL BE GIVEN TO DETECTING INTERMITTENT ELECTRICAL CONTACTS.

$\boxed{12}$. STAKE THREADS BETWEEN RETAIN (ITEM 2) AND NUT (ITEM 5)USING ADHESIVE (ITEM 15)PER DV-PP-3. CURE ADHESIVE FOR 2 HOURS AT 165°. APPLY ADHESIVE SPARINGLY TO AVOID SPREADING OUT TO FULL DIA. OF NUT. CONTACT OF THREADS NEED NOT EXCEED 90° OF ARC.

13. TEMPERATURE CYCLE TEST PER THE REQUIREMENT OF SPEC 98711.

$\boxed{14}$. IDENTIFICATION MARKING FOR THIS PART SHALL PER DV-PSN-3-C2B. PART NO. MAY CONSIST OF LAST 3 DIGITS OF DRAWING NO. AND APPROPRIATE DASH NO.

15. PART NO. 186732-1 IS AN INTERCHANGEABLE PART.